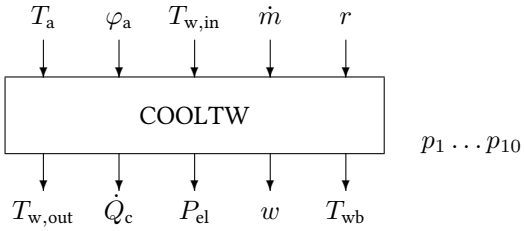
## Block COOLTW

The COOLTW simulates the cooling performance, the electricity and water consumption of an open cooling tower in counter-flow arrangement in dependency of the fill packing size and the perfromance data given on the data sheet for nominal operation conditions






| | |
|---|---|
| **Name** | COOLTW |
| **Function** | st0030 |
| **Inputs** | 5 |
| **Outputs** | 5 |
| **Parameters** | 10 |
| **Strings** | 0 |
| **Group** | S |

### Inputs

1 Ambient air temperature / °C
2 Relative humidity ambient air
3 Inlet water temperature / °C
4 Water mass flow rate / kg $s^{-1}$
5 Air mass flow rate in percent of nominal mass flow rate (20 - 100 %) / %

### Outputs

1 Outlet water temperature / °C
2 Recooling power of the cooling tower / kW
3 Required electricity power of the ventilator / kW
4 Overall water consumption / kg $h^{-1}$
5 Wet bulb temperature ambient air / °C

### Parameters

1 Nominal recooling power of the cooling tower / kW
2 Water inlet temperature under design conditions / °C
3 Water outlet temperature under design conditions / °C

| | |
|---|---|
| 4 | Water mass flow rate under design conditions / $\mathrm{kg\,s^{-1}}$ |
| 5 | Ambient air temperature under design conditions / °C |
| 6 | Wet bulb temperature under design conditions / °C |
| 7 | Electrical power consumption of the ventilator motor under design conditions / kW |
| 8 | Height of fill packing / m |
| 9 | Water consumption through spray losses per kW cooling power / $\mathrm{kg\,h^{-1}}$ |
| 10 | Water exchange rate per kW cooling power to avoid inrease of salt concentration / $\mathrm{kg\,h^{-1}}$ |

Strings

None

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Description

The COOLTW simulates the cooling performance, the electricity and water consumption of an open cooling tower in counter-flow arrangement in dependency of the fill packing size and the performance data given on the data sheet for nominal operation conditions.

In wet cooling towers mostly latent heat transfer is used to lower the temperature of the cooling fluid. Open cooling towers generally work with water as cooling fluid which is distributed over a fill packing and forced air-cooled by a ventilator. Partial evaporation of approximately 2–3% of the water as well as convective heat transfer between water and ambient air result in the cooling effect. Due to the evaporation of water outlet temperatures of the cooling water blow the ambient air temperature can be reached, which are only limited by the wet bulb temperature of the ambient air.

Fundamentals

The effect of cooling water by evaporation, like it is used in open cooling towers, will at first be described for an ideal process. Therein an air mass flow is passed over a free surface of water having the same temperature as the boundary water layer. Because of atomic interactions a water mass flow sets in motion and cools down the water. Thus overall energy balance can be described as follows.

$$\dot{m}_{\mathrm{w}} \cdot c_{\mathrm{p,w}} \cdot (T_{\mathrm{w,in}} - T_{\mathrm{w,out}}) = \dot{m}_{\mathrm{a}} \cdot (h_{\mathrm{a,out}} - h_{\mathrm{a,in}})$$

where

| | |
|---|---|
| $T_{\mathrm{w,in}}$ | Water inlet temperature / °C |
| $T_{\mathrm{w,out}}$ | Water outlet temperature / °C |
| $h_{\mathrm{a,in}}$ | Air inlet enthalpy / $\mathrm{kJ\,kg^{-1}}$ |
| $h_{\mathrm{a,out}}$ | Air outlet enthalpy / $\mathrm{kJ\,kg^{-1}}$ |
| $c_{\mathrm{p,w}}$ | Water heat capacity / $\mathrm{kJ\,kg^{-1}\,K^{-1}}$ |
| $\dot{m}$ | Mass flows of air (a) and water (w) / $\mathrm{kg\,s^{-1}}$ |

## Modeling

For an ideal process the temperature that can be reached, until the convective heat flow from air to water compensates for the latent heat flow from water to air via mass flow interaction, is called the air's wet bulb temperature $t_{\mathrm{wb}}$. Because this temperature can't be reached for a finite surface and time span, the recooling efficiency is introduced.

$$\eta = \frac{T_{\mathrm{w,in}} - T_{\mathrm{w,out}}}{T_{\mathrm{w,in}} - T_{\mathrm{wb}}}$$

with

| | |
|---|---|
| $T_{\mathrm{wb}}$ | Wet bulb temperature / °C |

Another parameter of wet cooling towers is the so called air ratio $\lambda$, which defines the relation between the used and the minimal air mass flow. It can be calculated from the effective and minimum air to water mass flow ratios $l_0$ and $l_{\mathrm{min}}$.

$$l_{\mathrm{min}} = \frac{\dot{m}_{\mathrm{a,min}}}{\dot{m}_{\mathrm{w}}}$$

$$l_0 = \frac{\dot{m}_{\mathrm{a}}}{\dot{m}_{\mathrm{w}}}$$

$$\lambda = \frac{l_0}{l_{\mathrm{min}}}$$

with

| | |
|---|---|
| $\dot{m}_{\mathrm{a,min}}$ | Minimum air mass flow rate / $\mathrm{kg\,s^{-1}}$ |
| $\dot{m}_{\mathrm{a}}$ | Air mass flow rate / $\mathrm{kg\,s^{-1}}$ |
| $\dot{m}_{\mathrm{w}}$ | Water mass flow rate / $\mathrm{kg\,s^{-1}}$ |
| $l_{\mathrm{min}}$ | Minimum air to water mass flow ratio |
| $l_0$ | Effective air to water mass flow ratio |
| $\lambda$ | Air ratio |

Also there is a clear correlation between the recooling efficiency $\eta$ and the air ratio. The characteristic behavior can be described using the following equation

$$\eta = C_{\mathrm{k}} \cdot (1 - \exp(-\lambda))$$

with

| | |
|---|---|
| $C_{\mathrm{k}}$ | Cooling tower constant |

After presenting the cooling tower constant $C_{\mathrm{k}}$, which can be calculated using design conditions, a simple open cooling tower model can be built. The advantage of using the presented equation is the minimal number of necessary parameters. In order to even simplify the parameterization, an empirical relationship between the cooling tower

constant and the height of the fill packing $H$ has been derived from typical values and is now used in this model.

$$C_{\mathrm{k}} = -0.5625 \cdot H^2 + 1.26 \cdot H + 0.3221$$

According to the proportional law for axial and radial ventilators the following general correlation of the electricity power consumption to the third power of the fan speed is given.

$$P_{\mathrm{el}} = P_{\mathrm{el,d}} \cdot \left( \frac{n}{n_{\mathrm{d}}} \right)^3$$

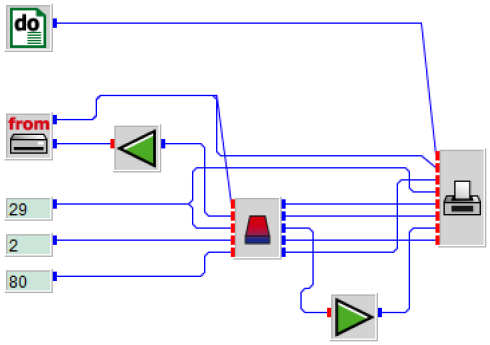
| | |
|---|---|
| $P_{\mathrm{el}}$ | Electric power demand at n / W |
| $P_{\mathrm{el,d}}$ | Electric power demand at design conditions / W |
| $n_{\mathrm{d}}$ | Number of revolutions per second of the cooling tower fan / $\mathrm{s}^{-1}$ |
| $n_{\mathrm{d}}$ | Number of revolutions per second of the cooling tower fan at design conditions / $\mathrm{s}^{-1}$ |

Implementation

This subsection presents the algorithm used in order to calculate the open cooling tower.

1. Parameters from design (d) conditions: $l_{\mathrm{min,d}} \rightarrow \eta_{\mathrm{d}} \rightarrow \lambda_{\mathrm{d}} \rightarrow l_{\mathrm{0,d}}$
2. Calculate the air mass flow: $\dot{m}_{\mathrm{a}} = l_{\mathrm{min,d}} \cdot \dot{m}_{\mathrm{w,d}} \cdot \frac{n}{n_{\mathrm{max}}}$ with the number of revolutions per second of the fan $n$
3. Determine the new effective air to water mass flow ratio $l_0 = \frac{\dot{m}_{\mathrm{a}}}{\dot{m}_{\mathrm{w}}}$
4. Estimate the wet bulb temperature with the assumption of isenthalpic humidification via iteration $x_{\mathrm{wb}} = f(\varphi(x), T(x))$ and a relative humidity $\varphi = 100\%$
5. Calculate the working condition parameters with the wet bulb temperature $l_{\mathrm{min}} \rightarrow \eta \rightarrow \lambda \rightarrow T_{\mathrm{w,out}}$
6. Estimate the air outlet temperature with the assumption of isenthalpic humidification via iteration $x_{\mathrm{a,out}} = f(\varphi(x), T(x))$
7. Calculate electric power consumption at $n$

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A DO block drives a READ block to read 96 records from the file `iseyear7.dat`, located in the `examples/data` directory. The records contain ambient temperature data in degrees Celsius and relative humidity in percent. An ATT block normalizes the percent values as required by the COOLTW block.

A PLOT block shows all outputs of the COOLTW block as a function of time.

